

## ON THE BINARY NATURE OF DUST-ENCIRCLED BD+20 307

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## ABSTRACT

Three epochs of high resolution spectra of the star BD+20 307 show that it is a short period ( $\sim 3.4$  day) spectroscopic binary of two nearly identical stars. Surprisingly, the two stars, though differing in effective temperature by only  $\sim 250$  K and having a mass ratio of 0.91, show very different Li line equivalent widths. A Li 6707Å line is only detected from the primary star, and it is weak. This star is therefore likely to be older than 1 Gyr. If so, the large amount of hot circumbinary dust must be from a very large and recent, but very late evolutionarily, collision of planetesimals.

*Subject headings:* stars: individual (BD+20 307) — binaries: spectroscopic — circumstellar matter

## 1. INTRODUCTION

Debris disks older than  $\sim 10$  Myr containing dust at temperatures  $> 100$  K are extremely rare (Aumann & Probst 1991; Silverstone et al. 2006). When warm dust does appear, it is likely to be from a stochastic event, perhaps akin to our own solar system's "Late Heavy Bombardment," at about 600 Myr after formation. Late episodes of dust production may signal the presence of a planetary system undergoing architectural reconfiguration (Gomes et al. 2005).

BD+20 307 is one of the few examples of a non-young star with hot debris (Song et al. 2005). It has a ring of dust at  $\sim 0.5$  AU (Weinberger et al. 2008). In order to understand the implications of the large amount of close-in dust, it would help greatly to know the age of the star. Song et al. (2005) used the Li 6707Å equivalent width and chromospheric activity to suggest an age of  $\sim 300$  Myr.

New observations reported here show that BD +20 307 is actually a spectroscopic binary. I reexamine the evidence for the age of the star.

## 2. OBSERVATIONS

The Magellan Inamori Kyocera Echelle (MIKE) spectrograph on the Clay (Magellan II) telescope was used to observe BD +20 307 on three consecutive nights – 2007 October 24–26 (UT). The  $0.35''$  wide  $\times 5''$  long slit provided a resolution of about 55,000 at wavelengths 3400 – 7250 Å. Seeing was  $\sim 0.5''$  on the first two nights and  $0.8$ – $1.2''$  on the third. On all three nights, data were obtained with an iodine cell in place to facilitate looking for planets around the star, and on the first night an observation without the iodine cell was also obtained. I do not use the iodine lines for the radial velocity analyses that follow. An observing log is given in Table 1.

The spectra were flattened, extracted and wavelength calibrated using the MIKE pipeline written by D. Kelson with methods described in Kelson et al. (2000); Kelson (2003); Kelson et al. (2006). The two observations from the first night were averaged. The signal-to-noise ratio (S/N) per pixel was  $> 100$  for wavelengths  $> 4000$  Å on the first two nights, except in the region of maximal io-

TABLE 1  
OBSERVING LOG

Date (UT)	Time	Int. Time (s)
2004 Aug 24	08:28:20	700
2007 Oct 24	04:35:20	600
2007 Oct 25	04:45:43	600
2007 Oct 26	04:12:33	600

dine absorption around 5000Å. The S/N was about 50% worse on the third night due to the worse seeing.

BD +20 307 was also observed on 2004 August 24 with the echelle spectrograph on the 2.5 m du Pont Telescope at Las Campanas Observatory. These data cover wavelengths  $\sim 4000$ – $9000$ Å and have a resolution of about 25,000 and S/N of 30–100. The data were extracted and calibrated using standard IRAF tasks.

Heliocentric and barycentric velocities were calculated with the RVSAO package in IRAF.

## 3. RESULTS

Two sets of lines are clearly visible in all three nights of MIKE data. To obtain the velocities of the double-lined spectroscopic binary, cross-correlations with a synthetic spectrum with effective temperature 6000 K and  $\log(g)=5.0$  were performed. This spectrum was generated using R. O. Gray's SPECTRUM code and line list<sup>1</sup> and a Castelli-Kurucz model atmosphere with solar metallicity<sup>2</sup>. The xcsao package in IRAF was used to compute the cross-correlations, and the two peaks were fit with parabolas in IDL. The uncertainty in the velocities was computed as the standard deviation of the velocities in the 40 different orders used. Results are reported in Table 2 and shown in Figure 1. On all three nights, the primary star produced a higher cross correlation peak.

The same cross-correlation was done for the lower resolution du Pont spectrum. A double-peaked cross-correlation appears only for the lowest two orders (4000–4150Å). I do not consider this detection of the binary reliable, and do not include these RV data in the analyses which follow.

<sup>1</sup> <http://www.phys.appstate.edu/spectrum/detail.html><sup>2</sup> <http://kurucz.harvard.edu/grids/gridP00aODFNEW/ap00k0odfnew.dat>

TABLE 2  
MEASURED RADIAL VELOCITIES

Component	HJD		
	2454397.6969	2454398.7041	2454399.6810
Primary	$-1.63 \pm 0.46$	$-51.34 \pm 0.62$	$4.92 \pm 0.79$
Secondary	$-17.49 \pm 0.85$	$38.03 \pm 0.64$	$-21.24 \pm 0.67$

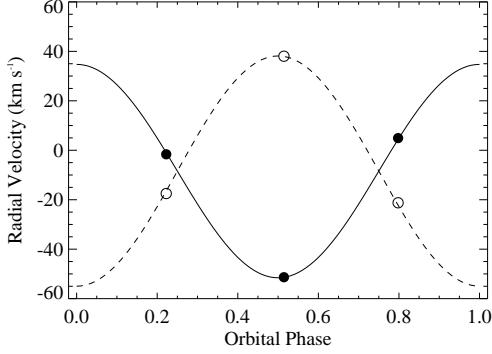


FIG. 1.— Velocities for the primary (filled circles) and secondary (open circles) components of the binary phased with an orbital period of 3.448 d. The residuals between the fit orbit and the data are  $<1 \text{ km s}^{-1}$  on each point.

TABLE 3  
EQUIVALENT WIDTH (IN mÅ) OF Li 6707Å LINE

Date	Combined Primary	Continuum Secondary	Separate Primary	Continuum Secondary
2004 Aug 24	$41 \pm 3$	...	$70 \pm 5$	...
2007 Oct 24	$35 \pm 2$	...	$60 \pm 4$	...
2007 Oct 25	$34 \pm 2$	$<6 (3\sigma)$	$58 \pm 4$	$<14 (3\sigma)$
2007 Oct 26	$33 \pm 2$	...	$56 \pm 4$	...

On all nights a Li 6707Å line was detected from the primary star (Figure 2). The equivalent widths were computed using direct integration over the lines relative to the combined continua from the two stars. Uncertainties from the pipeline reduction were used to give the statistical uncertainty. An additional systematic uncertainty was estimated by choosing different methods of finding the continuum and recomputing the equivalent widths. A  $3\sigma$  upper limit on the secondary's Li line was placed using the data from 2007 October 25, when the two stars were separated by  $89 \text{ km s}^{-1}$  ( $2 \text{ Å}$ ). These equivalent widths are given in the first two columns of Table 3.

The continuum normalized spectrum on 2007 October 25, which has the maximum separation of the two stars, was fit with a combination of synthetic spectra calculated with SPECTRUM from Castelli-Kurucz model atmospheres with solar metallicity. Free parameters were two effective temperatures, a single  $v \sin i$ , a single  $\log(g)$ , and two normalizations. One blue and one red region of the spectrum were fit  $-4099\text{--}4360 \text{ Å}$  and  $6282\text{--}6549 \text{ Å}$ . The best fit in both cases had  $T_{\text{eff}}=6500 \text{ K}$  and  $6250 \text{ K}$  for the primary and secondary stars, respectively and  $\log(g)=5.0$ . Contours of chi-square indicate the uncertainty is within 250 K (the gridding of the models) in  $T_{\text{eff}}$ . The lines are measurably broader than the ThAr

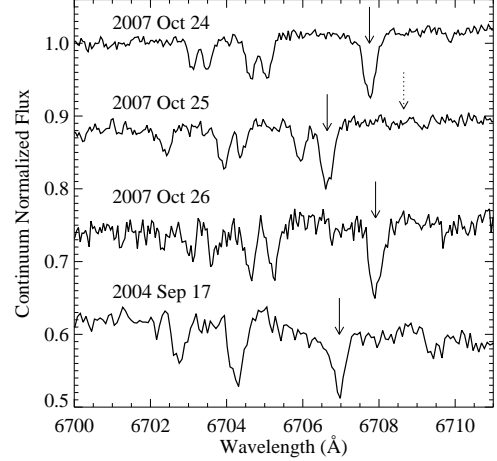


FIG. 2.— A Lithium 6707Å line is detected from the primary star in all four epochs (solid arrows). These spectra have been continuum normalized and offset for clarity. The best upper limit ( $14 \text{ mÅ}$ ,  $3\sigma$ ) on the secondary's Li line can be obtained on 25 Oct; the dashed arrow shows where it should be located.

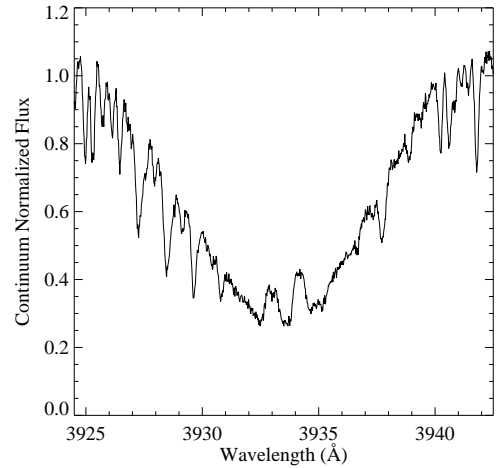


FIG. 3.— Closeup of the calcium K line from 2007 October 25 showing a weak central reversal for each star. The secondary star's reversal (red-ward line) is stronger. The spectrum was continuum normalized.

calibration lamp lines at the same wavelengths. The best fit models had  $v \sin i = 10 \pm 1 \text{ km s}^{-1}$ .

To compute the stars' Li equivalent widths relative to their own stellar continua, the flux ratio of the two stars must be obtained at 6707Å. Synthetic spectra were fit as above to the region at  $6645\text{--}6835 \text{ Å}$ . The best fit flux ratio was  $1.397 \pm 0.007$ . However, this statistical uncertainty probably underestimates the systematics from how the models are calculated. Applying this flux ratio to the measured equivalent widths makes the primary and secondary equivalent widths increase by factors of 1.709 and 2.387, respectively. The computed equivalent widths are given in the last two columns of Table 3.

The spectra were examined for evidence of chromospheric activity. Both stars show weak central reversals on their Ca H and K lines (Figure 3) that change in velocity along with the stars. The Balmer lines show no central reversals.

The velocities were fit for the stellar mass ratio (secondary/primary) yielding  $0.91 \pm 0.02$  and the line of sight radial velocity yielding  $\gamma = -8.8 \pm 0.6 \text{ km s}^{-1}$ .

Although the small number of observations prohibit the calculation of the full binary orbit, I tested whether a circular orbit could fit the velocities. The best fit produced reasonable residuals ( $< 1 \text{ km s}^{-1}$ ) for an orbit with a period of 3.448 days,  $\gamma = -8.4 \text{ km s}^{-1}$ , consistent with the fit above, and mass ratio 0.93, again consistent with the fit above. This orbit, shown in Figure 1 yields  $m \sin^3 i$  for each star – 0.13 and 0.12 for the primary and secondary stars respectively. I estimate the true masses of the stars as 1.3 and 1.2  $M_{\odot}$  based on the effective temperatures (6500 and 6250 K) obtained in the spectral fit described in § 3 and the MK spectral-type calibration given in Drilling & Landolt (2000); these masses are uncertain by  $\sim 0.1 M_{\odot}$ . Calculating the inclination from these masses yield  $27.8 \pm 0.8^{\circ}$ .

The fit, assuming the inclination of  $28^{\circ}$ , gives semi-major axes for the binary orbits of 4.4 and  $4.7 \times 10^6 \text{ km}$ . The stars should have radii of 1.3–1.6  $R_{\odot}$ , so their separation is about 9 stellar radii.

#### 4. DISCUSSION

Of primary interest for understanding the dusty debris disk around BD+20 307 is the age of the system.

Although the orbit is not well measured, a reasonable fit is obtained with  $e=0$ . Binaries of any age with periods less than  $\sim 8$  days are found in circular orbits (Mathieu et al. 1992; Melo et al. 2001). So,  $e=0$  is consistent with the 3.4 day period and is no indication of the age of the system.

The formation of close binaries may depend on the presence of another star in the system; Tokovinin et al. (2006) find that 80% of binaries with periods  $< 7$  days are actually in higher order multiple systems. It is unknown whether BD+20 307 has another, wider, component, but this should be investigated.

Taking  $\sin i = 28^{\circ}$  from the spectral modeling, the rotational velocity of the stars is  $21 \text{ km s}^{-1}$ . A standard radius for a  $T_{\text{eff}}=6250 \text{ K}$  star would be 1.3  $R_{\odot}$ , but solar-like stars with active chromospheres have somewhat larger radii than their non-active counterparts (Torres et al. 2006). Stellar radii of 1.3 – 1.6  $R_{\odot}$  correspond to rotational periods of 3 – 3.7 d. The close agreement between the rotation period and the orbital period suggests that the stars are tidally synchronized.

The timescale for synchronization for stars of mass similar to the Sun is given by Zahn (1992), and for equal mass components is  $\approx 10^4 P^4 \text{ yr}$  where  $P$  is the orbital period. Given a period of 3.5 d,  $t_{\text{synchron}} is 100 \text{ Myr}$ . This provides a lower limit to the age of the system.

Tidal coupling in a close binary can give rise to enhanced magnetic activity (Rottler et al. 2002). So, the central reversals observed in both stars' Ca H and K lines need not arise from youth but could be from their interaction.

For stars with deep convective zones, there is a tight correlation between lithium abundance with age and spectral type, but for stars with  $T_{\text{eff}} \sim 6500 \text{ K}$ , there is little Li depletion by the age of the Hyades (Soderblom et al. 1990). A typical Li equivalent width for a star with B-V of 0.5 in the Hyades is 90 mÅ, 1.5 times that for BD+20 307. Furthermore, tidally

locked systems in the Hyades show inhibited Li depletion (Barrado y Navascues & Stauffer 1996).

The situation for older stars is more complex. Stars even hotter than the Sun apparently do deplete Li after reaching the main sequence. Sestito & Randich (2005) summarize the Li abundances in open clusters of various ages, including the wide spread in abundances among members of old ( $> 1 \text{ Gyr}$ ) clusters. Hot stars can show substantial depletions. For example in the 1 Gyr old cluster NGC 3960, stars with  $B - V \approx 0.5$  ( $T_{\text{eff}} \sim 6250 \text{ K}$ ) show a range EW(Li) of  $< 10$  to 80 mÅ (Prisinzano & Randich 2007).

Initial metallicity can have a large effect on main sequence Li abundance, but given their tight orbit, the two stars in BD+20 307 presumably formed from the same molecular cloud material at the same metallicity. Martín et al. (2002) found that  $\sim 20\%$  of wide field binaries showed disparate Li. Stars may also be polluted by Li and other elements during planetary evolution (e.g. Gonzalez 2006), which could account for differences in Li abundance between wide binaries and within clusters that should have the same initial metallicity. Especially for stars with small convective zones, like the components of BD+20 307, material deposited should last for the entire main sequence lifetime. The tightness of the BD+20 307 orbit means that any planets must be circumbinary. If disparate pollution were to occur, it might be expected to favor the more massive star. It is indeed the primary star that shows the greater Li line strength.

Taken together, the modest Li line strength of the primary and very low Li line strength for the secondary argue for an old age of the system, certainly greater than that of the Hyades and probably  $> 1 \text{ Gyr}$ . In this case, the dust generating event happened quite late. In the Solar System, the last era of major planetesimal removal happened at an age 600-800 Myr (Strom et al. 2005).

It is further tempting to speculate on what happens to the dust ring over time. Poynting-Robertson and solar wind drag should cause the grains at 0.55 AU to fall onto the central stars on timescales  $< 1000 \text{ yr}$  (Weinberger et al. 2008). Meteorites in the Solar System contain Li, no matter where they formed in the original proto-planetary disk (Seitz et al. 2007). Thus the opportunity seems to exist for substantial stellar pollution with Li by the dust around BD+20 307. Perhaps this dust is being swept up by a body orbiting between the ring and the binary and thus cannot pollute the surface of the stars. A detailed abundance study of the stars could reveal the extent of any pollution.

#### 5. CONCLUSIONS

BD+20 307 is a spectroscopic binary composed of two similar stars of late F spectral-type in a short, rotationally synchronized orbit of  $\sim 3.4$  days. Standard chromospheric-age calibrations for single solar-type stars are therefore not applicable to this system. The binary is likely quite old,  $> 1 \text{ Gyr}$ , in order to allow the two stars to develop quite different lithium equivalent widths. The collision that produced the circumbinary dust ring must have happened recently, given the short timescale for removal of material at 0.5 AU, and could be expected to pollute the envelopes of the stars. That they have such low lithium could be evidence that the dust does not actually reach them.

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